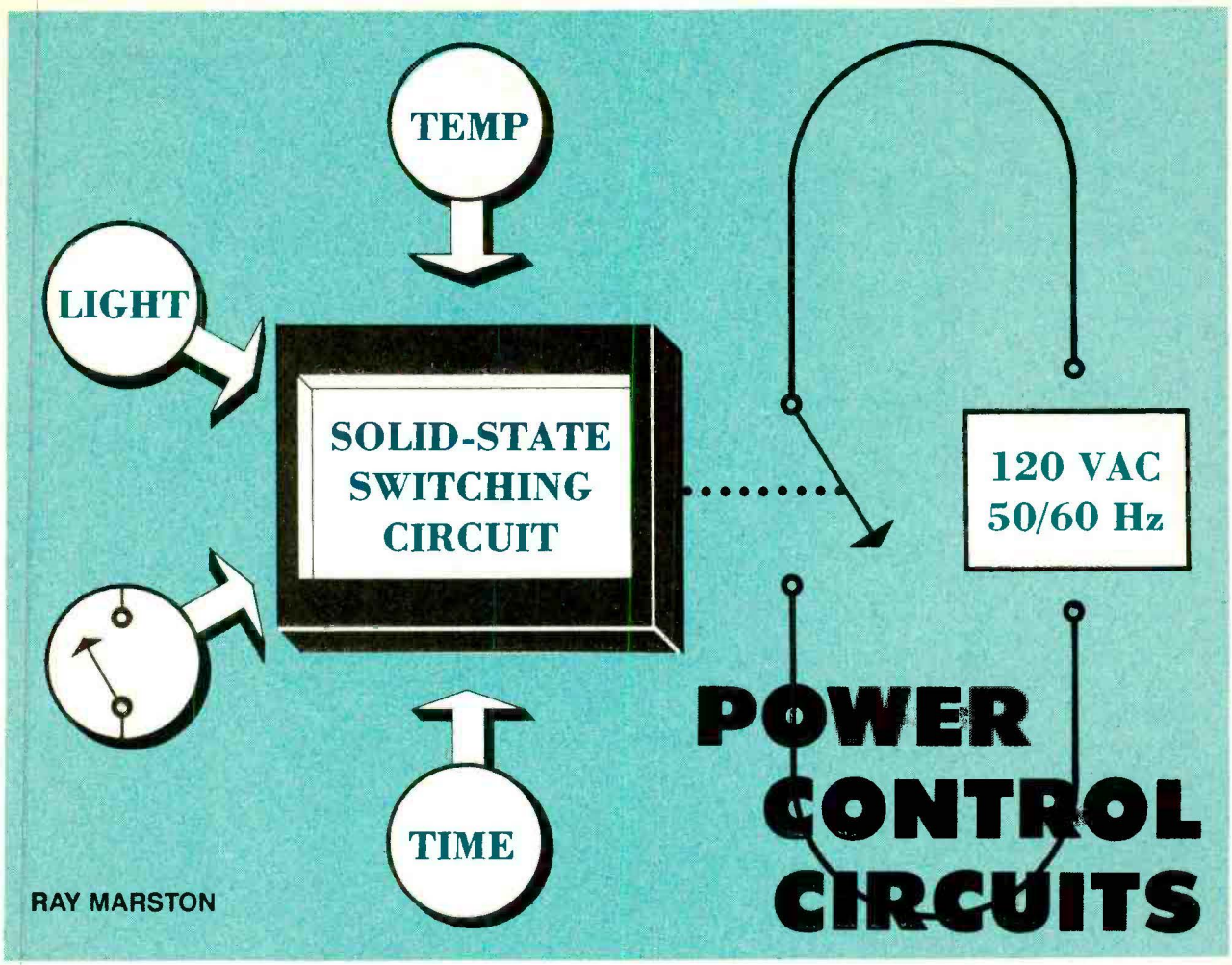


Learn to apply power semiconductors in practical power control circuits and control appliances, motors, and relays.

SOLID-STATE ELECTRONIC CONtrol circuits stand between you and the AC power line in appliances from washing machines to air conditioners. You'll also find them in light-switching circuits, power tools, and all manner of industrial equipment.

AC-powered equipment with electronic controls can be switched on and off by sensors that respond to changes in temperature, light level, pressure, air flow, liquid level, and other physical variables.

The low cost and ready availability of solid-state electronics has made switching the AC line convenient and economical. The miniature circuitry occupies very little space within the host appliance or product, and it consumes very little power on its own.

An article in last month's *Electronics Now* discussed power semiconductor devices—how they work, how they are made, how they are packaged, and their applications.

This artice will continue the "power control" theme by introducing a selection of practical, basic, ON/OFF AC power switching circuits.

Sync vs. async switching

Triacs are solid-state bidirectional thyristors that can operate in the 120-volt or 240-volt AC line and switch either polarity. A triac can be triggered (turned on and latched) either synchronously or asynchronously with the AC line. However, the triac will be turned off automatically at the end of each AC half-cycle (180 electrical degrees) as its terminal current falls below the device's *minimum holding* value. Asynchronous circuits can generate significant radio-frequency interference (RFI), particularly at initial turn-on

Synchronous circuits, which will be covered *always* turn on at the same point in each AC half-cycle (usually just after the zero-crossing point) and generate minimal RFI.

All of the circuits in this article perform asynchronous power switching. Figures 1 to 8 show a variety of asynchronous triac power-switching circuits that perform basic ON/OFF AC-line switching.

Triac switching circuits

Figure 1 is the schematic for a simple AC power switch that includes a triac. This circuit can switch AC power to lamps, heaters, motors, or many different

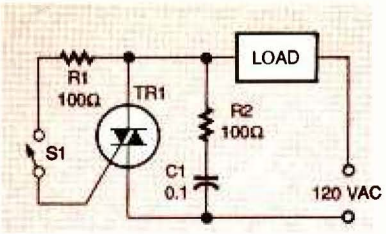


FIG. 1—SIMPLE AC POWER SWITCHING circuit with a triac that can be triggered from the AC line.

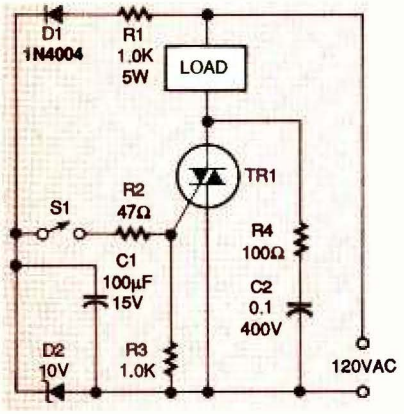


FIG. 2—AC POWER SWITCH whose triac can be triggered with line-derived DC.

kinds of appliances and machines. However, the triac for this circuit must be selected with the necessary rating to switch AC power safely for your intended application. *Caution:* The components for all of the schematics in this article have been selected for switching *only* 120-volt, 50/60 Hz AC.

In Fig. 1, the triac is off and acts like an open switch when S1 is open. However, it acts like a closed switch that is gated on from the AC line through the load and R1 shortly after the start of each AC half-cycle, when S1 is closed. The triac's main terminal voltage drops to only a few hundred millivolts when the triac turns on, so R1 and S1 consume very little current.

Keep in mind that the triac's threshold is *not* synchronized to the AC line when S1 is initially closed, but it becomes synchronized on all subsequent half-cycles. Resistor R1 and capacitor C1 form a *snubber* network that (as was described last month) suppresses voltage spikes that occur when inductive loads are switched and current and voltage are out-of-phase. Snubber networks are included in all of the triac circuits presented in this article.

Figure 2 shows how the triac functions as a power switch that can be triggered by the AC line-derived DC supply. Capacitor C1 is charged to +10 volts on each positive line half-cycle through resistor R1 and Zener diode D1. The charge on C1 triggers the triac when S1 is closed. Notice that resistor R1 is subjected to close to the full AC line voltage at all times. Consequently, it must have a high power rating (5 watts here).

Caution: All parts of this circuit are "live" so the circuit poses a life-threatening electrical-shock hazard. Moreover, this circuit is difficult to interface with external control circuitry because it does not include an isolator or matching device.

Isolated input control

Figure 3 shows how the circuit in Fig. 2 can be modified so that it can easily be interfaced to external control circuitry. Here, switch S1 is replaced by bipolar junction transistor Q1, which is driven by the output stage of an optocoupler (or optoisolator) IC1. It consists of an infrared light-emitting diode (IRED) optically coupled to a phototransistor. Any of a number of industry-standard transistor-output optoisolators will work here.

These include the TIL111, TIL 112, 4N27, and 4N28. The optocoupler can be driven from a 5-volt or greater DC supply through resistor R1. The triac turns on only when the input circuit supply is connected to the 5-volt or greater power source by switch S1.

As was pointed out in last month's article, optocouplers

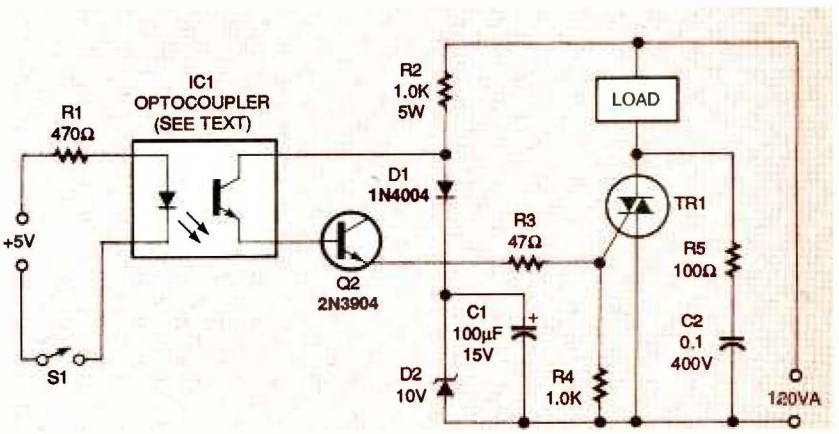


FIG. 3—OPTICALLY COUPLED AC power switch with a triac that can be triggered by DC input.

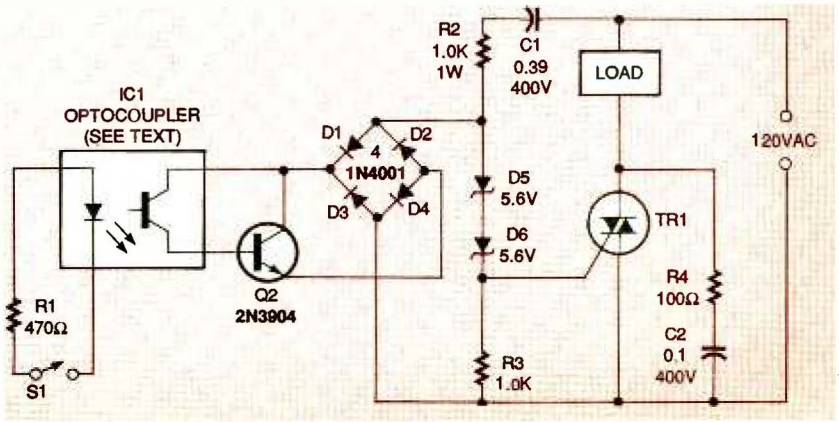


FIG. 4—OPTICALLY COUPLED AC power switch with a triac that can be triggered by AC input.

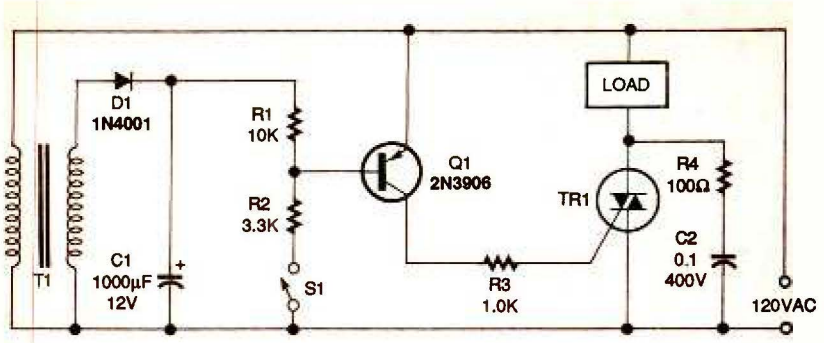


FIG. 5—AC POWER SWITCH with transistor-aided DC triggering and transformer isolation

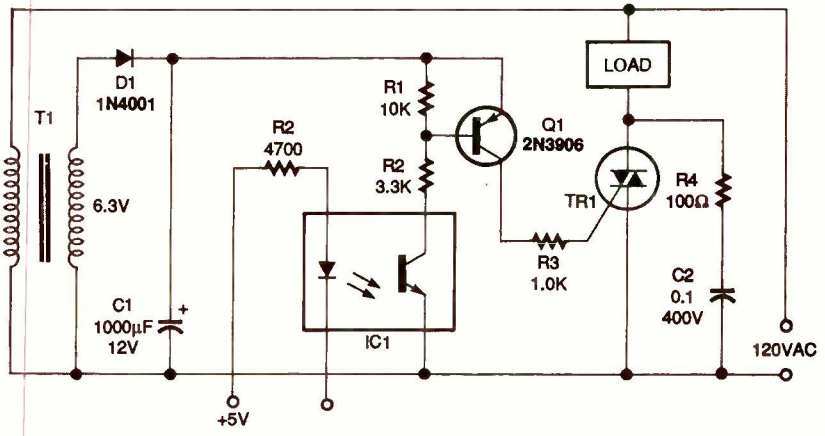


FIG. 6—OPTOISOLATED-INPUT AC power switch with DC triggering and transformer isolation.

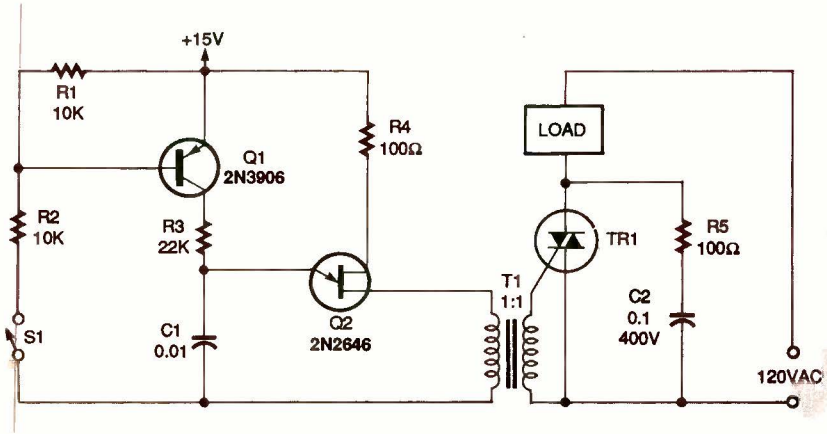


FIG. 7—TRANSFORMER ISOLATED AND COUPLED triac AC power switch with a unijunction transistor

have typical isolation ratings (V_{ISO}) of 5000 volts AC, and some have ratings as high as 7500 volts AC. This means that the input circuit (think of it as the "coil" circuit of an electromechanical relay) is fully isolated from the AC line-driven triac output circuit (think of it as the "contact" circuit of an EM relay).

This basic circuit can be designed to give any desired form of automatic "remote" triac switching by replacing S1 with a suitable electronic sensor.

Figure 4 is a variation of the Fig. 3 circuit. In this schematic, the triac is AC triggered on each line half-cycle through capacitor C1 and resistor R1 in series and back-to-back Zener diodes D5 and D6. The AC line impedance of C1 determines the magnitude of the triac gate current, but C1's power dissipation is near zero.

The bridge rectifier consisting of D1, D2, D3, and D4 is connected across the series network of Zener diodes D5 , D6 and R3, which is loaded by transistor Q1. When transistor Q1 is off, the bridge is effectively open, and triac TR1 turns on shortly after the start of each AC half-cycle.

When transistor Q1 is conducting, a near short-circuit appears across D5, D6, and R3, inhibiting the Triac gate circuit, and triac TR1 is off. Transistor Q1 is actually driven by the optocoupler from the isolated external input circuit, so the triac is normally on, but it turns off when S1 is closed.

DC triggering

Figures 5 and 6 show several ways to trigger a triac power switch with a transformer-derived DC power supply and a transistor-aided switch. In the Fig. 5 circuit, the transistor and the triac are both driven on when S1 is closed, and they are off when S1 is open.

Switch S1 in Fig. 5 can be be replaced by a sensitive switch that will respond to physical changes. For example, a thermistor can trigger the circuit if the ambient temperature falls below a specified set point. Similarly, a photoconductive cell can respond to changes in light level, a pressure sensor to changes in air or liquid pressure, and a flowmeter to changes in a liquid or air flow rate. Notice, however, that the Fig. 5 circuit is "live" and presents a shock hazard.

Figure 6 shows how the Fig. 5 circuit can be modified for control by an optocoupler. This will permit it to be activated by fully isolated external circuit.

Unijunction triggering

Figures 7 and 8 show several alternative ways to trigger a triac from a fully isolated external circuit. In these two circuits the triggering action is obtained from a unijunction transistor

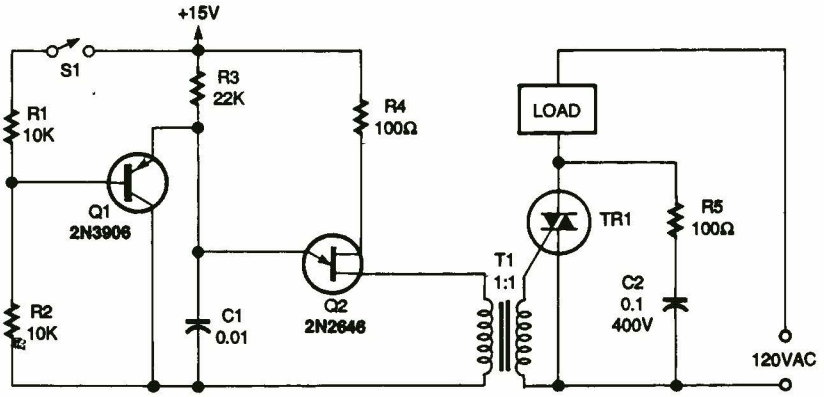


FIG. 8—TRANSFORMER-ISOLATED AND COUPLED triac AC power switch with a unijunction transistor.

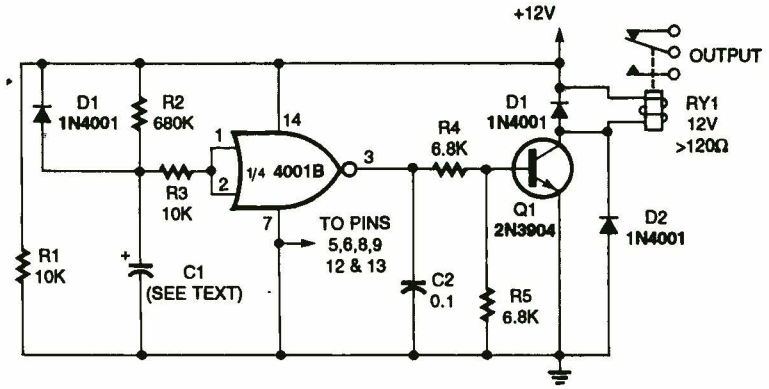


FIG. 9—AUTOMATIC TURN-OFF relay switching circuit.

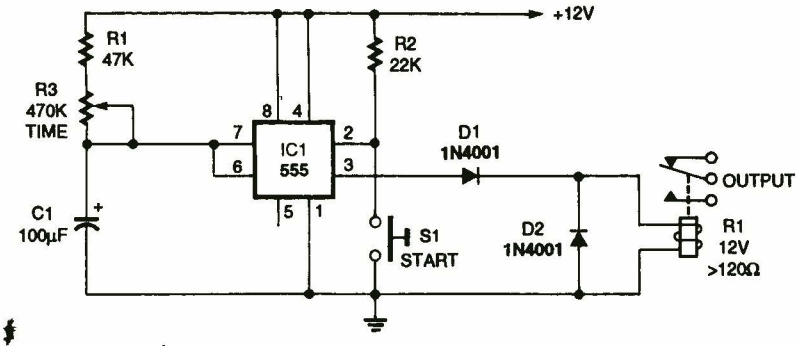


FIG. 10—SIMPLE 6 TO 60-SECOND timer circuit.

(UJT) configured in a pulse-generating relaxation oscillator.

In these two circuits, the triggering action is obtained from the oscillator circuit that includes UJT Q2. It operates at a frequency of several kHz, and its output pulses are fed to the gate of triac TR1 through pulse transformer T1, which provides the desired isolation.

Because of the UJT oscillators's fairly high operating frequency, the triac is triggered on within a few electrical degrees of the start of each AC half-cycle when the oscillator is on.

(For more on the UJT refer to the sidebar "What is a Unijunction Transistor?").

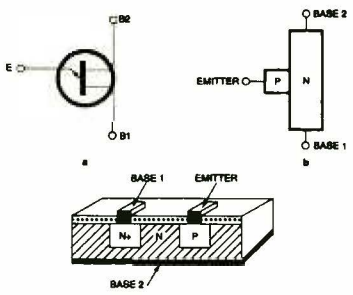
The UJT Q2 forms a relaxation oscillator when resistor R3 is placed between its emitter and base B2 where positive voltage is applied and a capacitor C1 is placed between the emitter and the base B1. When the capacitor voltage reaches a specified level, the UJT conducts and rapidly discharges the capacitor. The time for the capacitor to discharge can be calculated, and the frequency of the sawtooth is approximately 1/ time.

In the Fig. 7 circuit, Q1 is in series with the UJT's main tim-

What Is A Unijunction Transistor?

A *Unijunction transistor* (UJT) is a three-terminal silicon transistor with a single PN junction. Its input terminal is called the *emitter* and its two other terminals are called called base 1 and base 2. The important characteristic of the UJT is its *negative resistance* that occurs when the emitter is properly biased. It is this characteristic that makes it useful in pulse formation, timing, triggering, and various sensing applications.

The emitter of the N-channel UJT is connected to the P-type region of the PN junction and base terminals 1 and 2 are connected to the N-type region. The N-type region is lightly doped, giving it a high resistance in the absence of a positive emitter bias.



SCHEMATIC FOR AN N-channel UJT (a), functional diagram (b), and section view of a modern UJT made by the diffusion process(c).

If the emitter is grounded, the PN junction is reverse biased, and a small emitter reverse current flows. However, with a positive bias on the emitter, current flows from the emitter into the N-type region, causing the resistance of that region to decrease, resulting in more forward current. The device continues to conduct until the input is open-circuited or the emitter current is significantly reduced.

The arrowhead points in the direction of conventional current for a forward-biased N-channel UJT (from the P-type emitter to the N-type region). There is also a P-channel UJT whose schematic symbol is identified by the arrowhead directed outward.

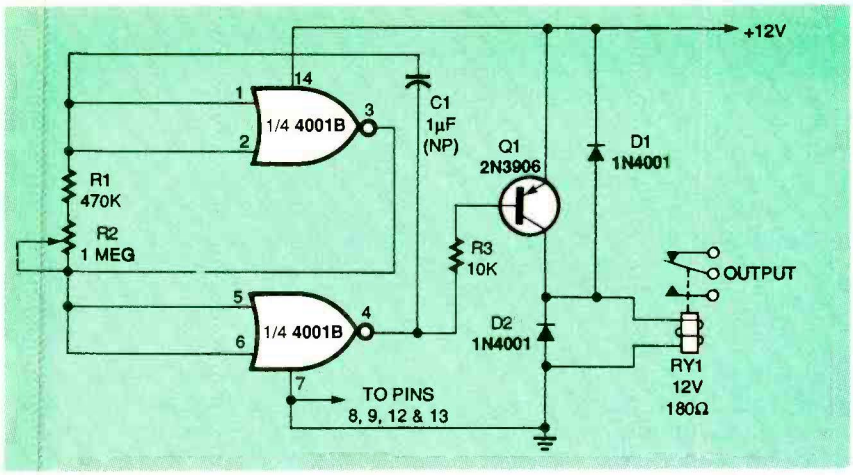


FIG. 11—RELAY PULSER circuit.

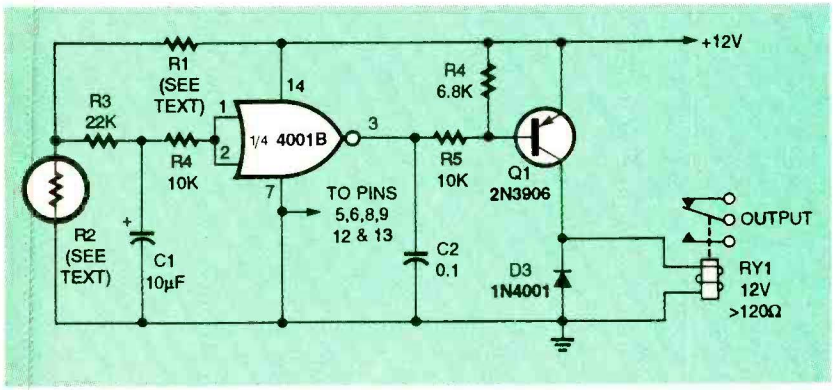


FIG. 12—LIGHT ACTIVATED RELAY switching circuit with transient suppression.

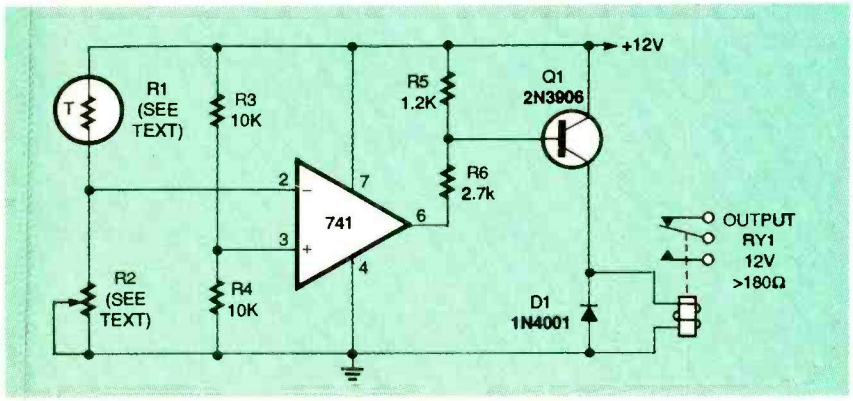


FIG. 13—PRECISION OVERTEMPERATURE relay switching circuit.

ing resistor R3, so the UJT and triac turn on only when S1 is closed.

In the Fig. 8 circuit, Q1 is in parallel with the UJT's main timing capacitor C1, so the UJT and triac turn on only when S1 is open. In both of these circuits, S1 can be replaced by a sensor or transducer to give some kind of automatic power-switching action as described earlier.

Automatic control

The triac circuits in Figs. 3 to 8 can be modified to provide automatic switching in response to a change in a physical variable such as temperature, time or light intensity. These changes can be translated into signals that turn the triac circuits on or off.

Figures 9 to 13 show some examples of automatic control circuits. All of these circuits have electromechanical relay outputs, enabling them to switch AC or DC power directly. Nevertheless, each circuit can be modified to drive a triac.

Time control

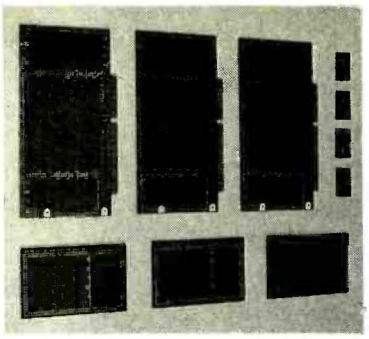
The most popular automatic control circuits respond to time delays. Figures 9 to 11 show circuits that offer a simple "timer" response. In this response, the relay turns on as soon as the circuit is activated, but then it turns off again automatically after a preset period.

The automatic turn-off switching circuit Fig. 9 works as follows: The NOR gate (one-fourth of an industry standard 4001B quad, two-input CMOS NOR gate IC) acts as a digital logic inverter. Its output is sent to the relay coil through NPN bipolar junction transistor Q1, and its output is obtained from the junction of the time-controlled voltage divider formed by resistor R2 and capacitor C1.

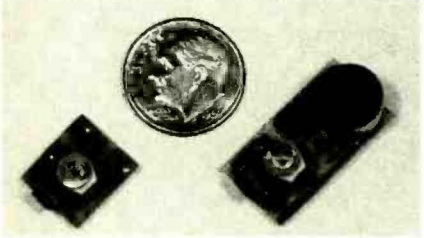
When power is first applied to the circuit, C1 is fully discharged. As a result, the inverter input is grounded and its output is at the full positive-supply voltage. Consequently, transistor Q1 and relay RY1 are driven on.

As soon as power is applied, C1 charges through resistor R2, and a rising exponential voltage appears at the inverter input. After a time delay determined by the R2-C1 time constant, this voltage rises to the threshold value of the CMOS inverter stage. As a result, the inverter gate output swings to logic low and switches Q1 and the relay off, completing the action. Diode D1 and resistor R1 ensure that C1 discharges rapidly as soon as power is removed from the circuit, giving the circuit a rapid reset feature.

The circuit in Fig. 9 has a time delay of about 0.5 second per microfarad of C1 value. This relationship permits the circuit to be designed for delays up to several minutes with the proper C1 value. If required, the delay can be made variable by replacing resistor R2 with a fixed resistor and a potentiometer in series.



BEST PROTO™ PROTOTYPING BOARDS INCLUDE LOW NOISE POWER AND GROUND PLANES, plated through holes, predefined sites for SMD passives, and signal names silk-screened on both sides. Engineer's kit (pictured) is **$129.50**, 16-bit ISA card is **$32.50**. Add $5 s&h (CA add 7.25% Sales Tax). Distributors wanted. **BEST PROTO, Dept E5, Box 232440, San Diego, CA 92193-2400 (619) 286-9000 ph/fax. Visa/MC.**



WORLD'S SMALLEST FM TRANSMITTERS! New Surface Mount Technology (SMT) makes all others obsolete! XST500 Transmitter—powerful 3 transistor audio amplifier, transmits whispers up to 1 mile. XSP250 Telephone Transmitter-line powered, transmits conversations up to ¼ mile. Both tune 88-108 MHz. Easy to assemble E-Z KITS (SMT components pre-assembled to circuit board)! XST500—**$44.95**, XSP250—**$34.95**, VISA/MC. COD add **$6. XANDI ELECTRONICS, 1270 E. Broadway Rd. #113, Tempe, AZ 85282, 1-800-336-7389.**

CIRCLE 111 ON FREE INFORMATION CARD

CALL NOW AND RESERVE YOUR SPACE

- 6 x rate $1,000.00 each insertion.
- Fast reader service cycle.
- Short lead time for the placement of ads.
- We typeset and layout the ad at no additional charge.

Call 516-293-3000 to reserve space. Ask for Arline Fishman. Limited number of pages available. Mail materials to: mini-ADS, ELECTRONICS NOW, 500-B Bi-County Blvd., Farmingdale, NY 11735.

FAX: 516-293-3115

This circuit offers only mid-range timing accuracy. However, greater accuracy can be obtained with a circuit that has an industry-standard 555 timer IC as its basic timing element. For example, consider the simple 6- to 60-second timer circuit (For more information on the 555 timer IC, refer to *Radio-Electronics*, September, October, November, and December, pages, 58, 69, 61, and 62, respectively.)

In the Fig. 10 circuit, a timing cycle is started when the START momentary switch S1 is closed. The contacts for relay RY1 close immediately, and capacitor C1 begins to charge towards the positive supply voltage through resistor R1 and potentiometer R3 until, after a delay determined by the potentiometer R3 setting, C1 rises to two-thirds of the supply voltage. At that time, the IC1 gate changes state and the relay turns off. The timing cycle is then complete.

The circuit in Fig. 11 is a simple relay pulse circuit that repeatedly switches relay RY1 on and off at a rate variable by adjusting potentiometer R2 between 26 and 80 cycles per minute through NPN transistor Q1. An astable multivibrator is formed by resistor R1, potentiometer R2 and the two 4001B NOR gates.

Heat/light control

Figures 12 and 13 are circuits that will activate a relay in response to variations in light or temperature levels. The circuit in Fig. 12 circuit acts as a *dark-activated* switch that closes the relay only when light intensity falls below a preset level. Potentiometer R1 and light-activated photoconductive cell R2 form a light-sensitive voltage divider.

Photoconductive cells are also known as light-dependent resistors, light-sensitive resistors, or photoresistors. In Fig. 12, the output of the photoconductive cell is filtered to suppress transients by the network consisting of R3 and C1 and fed to the input of the 4001B NOR gate. It functions as a logic inverter to close the relay contacts through transistor Q1.

Under bright light conditions, the resistance of the photoconductive cell is low, so the inverter input is logic low, its output is logic high, and both transistor Q1 and relay RY1 are off. Under dark conditions, the photoconductive cell R2 has a high resistance. As a result, the inverter gate input is high, its output is low, transistor Q1 is on and the contacts of relay RY1 are closed.

The precise illumination threshold level of the circuit can be varied by potentiometer R1. The photoconductive cell in this circuit can be any with a cadmium-sulfide resistive element whose resistance value is between 2 kilohms and 2 megohms at the desired illumination threshold level. In addition, the adjusted resistive value of potentiometer R2 should balance that of the photoconductive cell. (For more information on photoconductive cells, refer to the July 1992 *Radio-Electronics*, Page 63.)

Figure 13 is a schematic for a precision over-temperature relay switching circuit that turns a relay on when ambient temperature exceeds a preset level. In this circuit, a 741 operational amplifier IC1 and a PNP transistor Q1 are connected as a relay-driving precision voltage comparator.

The noninverting input is taken from the voltage divider formed by the junction of resistors R3 and R4, and the inverting input is taken from the temperature-sensitive voltage divider formed by thermistor R1 and potentiometer R2.

The thermistor for this circuit can be any resistive element with a negative-temperature-coefficient (NTC) that has a resistance value between 1 kilohm and 20 kilohms at the desired threshold. The resistance of potentiometer R2 should equal this value at the same temperature. This circuit can also be modified to act as a under-temperature switch by exchanging the positions of thermistor R1 and potentiometer R2. (For further information on thermistors, refer to *Radio-Electronics* March 1992, page 52.) Ω